ISSN 1054-660X, Laser Physics, 2008, Vol. 18, No. 10, pp. 1128–1130.

Diode-Pumped Q-Switched Tm:YAP Laser with a Pump Recycling Scheme

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Received May 6, 2008

Abstract—We reported on a diode end-pumped AO Q-switched Tm:YAP laser at 1937 nm. The average output power was 3.9 W, with a slope efficiency of 29.4% and optical–optical conversion efficiency of 21.6% at a 5-kHz repetition rate. The temperature dependency of the output power and the pulse width at different repetition rates were investigated in details.

PACS numbers: 42.55.Xi, 42.60.Gd

DOI: 10.1134/S1054660X08100034

1. INTRODUCTION

Solid-state lasers working in the 2-μm eye-safe spectral regions have received general interest in recent years, since there were many applications using two-micron lasers, such as atmosphere sensing, range-finding, and coherent laser radar [1]. Here, 2-μm Q-switched lasers were very attractive and necessary sources for optical parametric oscillators (OPOs) and solid-state lasers further in the mid-infrared spectral region [2–4]. The rare-earth ion Tm^{3+} doped laser materials were emerging as interesting active media for the 2-μm region due to the possibility of pumping directly by a high-power laser diode emitting at around 800 nm [5–8]. Laser operations based on several hosts such as YAP, YAG, and YLF etc. have been reported [9–11]. The laser host YAP was a biaxial crystal, which had the similar mechanical and physical properties to YAG, but the emission cross-section of thulium ion in YAP was twice that in YAG (6.0×10^{-20} and 2.9×10^{-20} cm^2, respectively) [12]. Additionally, the output wavelength was polarized due to the natural birefringence of YAP and diode-pumped Tm:YAP lasers had been reported both as CW and pulsed laser sources [13]. In 2004, Sullivan et al. reported a high-power acoustooptically Q-switched 1.94-μm Tm:YAP laser briefly. The Q-switched pulse energy was 7 mJ with a repetition rate of 5 kHz at a low temperature of –10°C [14]. Recently, Cai et al. demonstrated a room-temperature AO Q-switched 1.99-μm Tm:YAP laser. The crystal was *c*-cut, and the average output power was from 1.57 to 2.00 W as the repetition rate increased from 1 to 50 kHz [15].

In this article, we report on a room-temperature AO Q-switched Tm:YAP laser using a *a*-cut crystal. When the Tm:YAP crystal was controlled at 18°C, the 80-ns pulse duration was realized by the recycling pump method with an L-shaped resonator. In addition, we investigated the temperature dependency of the average output power and the pulse width at different repetition rates.

2. EXPERIMENTAL SETUP

The YAP crystal was *a*-cut (Pbnm), and doped with 4 at % thulium. The dimensions were 2.6×2.6 mm^2 in cross section and 5 mm in length. The faces were coated both antireflection in the 2-μm region and high-transmission coated at the pump wavelength. The laser crystal was mounted on a copper heat sink, with indium foil sandwiched between the sides of the medium and the heat sink. The temperature was controlled at 18°C by a thermoelectric cooler. The pump recycling scheme led to an uniform thermal load distribution and a high efficiency.

The experimental setup for the AO Q-switched Tm:YAP laser is shown in Fig. 1. The pump source was a 793-nm LD with a 200-μm pigtail fiber. The length of the physical cavity resonator was approximately 75 mm. The input mirror (M1) was a 250-mm radius concave, and it was coated with a high reflectivity ($R >$

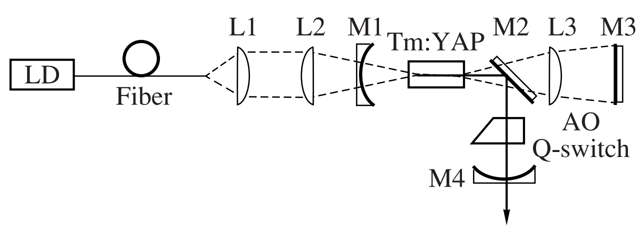

Fig. 1. Setup of the diode-pumped Tm:YAP laser.

99.5%) at 1.94 μm and a high transmissivity ($T > 91\%$) at 793 nm. The output coupler (M4) had a transmission of 14.1% at 1.94 μm. The radius of curvature of the output coupler was 200 mm. The pump LD divergent output of the diode was collimated by a 25-mm focal length spherical lens (L1) and then refocused onto a laser crystal by a 55-mm achromatic lens (L2). The 45° dichroic mirror (M2) provided both a high reflection at the resonated wavelength (99.5%) and a high transmission at the pump power (93%). The pump light transmitting the 45° dichroic mirror was recollected and refocused by the high reflector (M3) and a 51-mm lens (L3) on the other end.

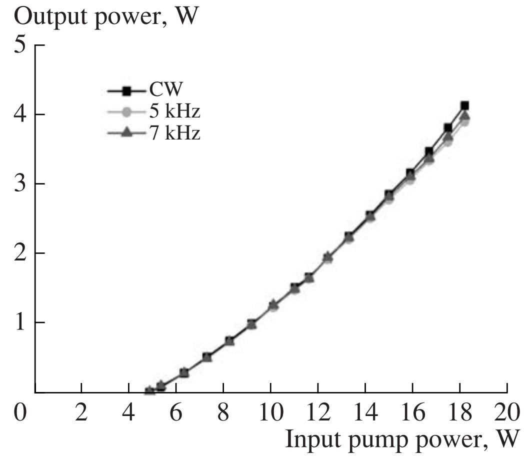

Fig. 2. Laser output power versus diode-pumped power.

3. EXPERIMENTAL RESULTS

The Tm:YAP output power as a function of the pump power is illustrated in Fig. 2. With the output cou-

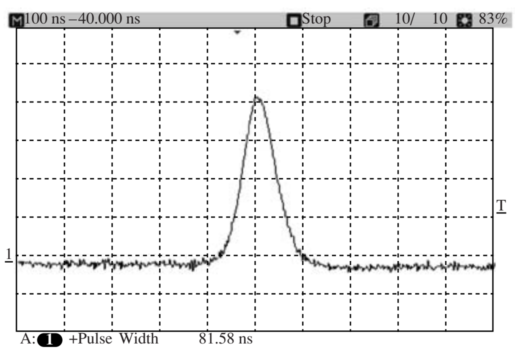

Fig. 3. Output pulse profile at a 5-kHz PRF and a pump power of 18.2 W.

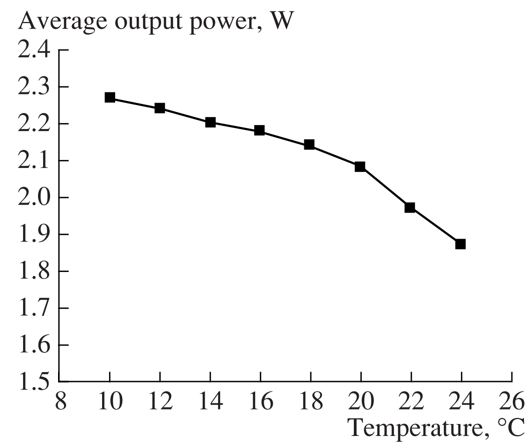

Fig. 5. Output power at different temperature of the crystal at 5 kHz and a pump power of 18.2 W.

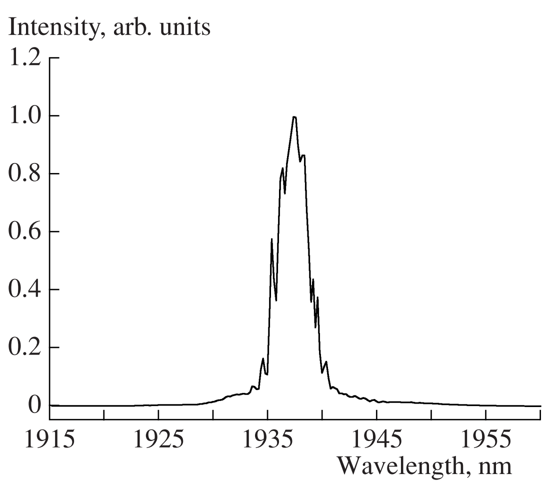

Fig. 4. Spectrum of Tm:YAP laser with a 14.1% transmission of OC.

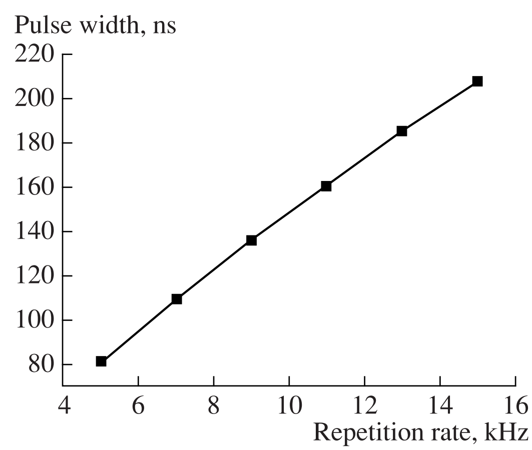

Fig. 6. Pulse width at different repetition rates with a pump power of 18.2 W.

pler transmission of 14.1%, the CW maximum output power was 4.2 W corresponding to a pump power of 18.2 W, resulting in a slope efficiency of 30.7% and total optical–optical efficiency of 22.8%. The threshold was 4.9 W. For the Q-switched operation, the average output power dropped to 3.9 W when the repetition rates were set at 5 kHz and 4.0 W at 7 kHz.

The temporal profile of the Q-switched pulse at a 5-kHz PRF was shown in Fig. 3. The pulse duration (FWHM) was about 80 ns at the maximum output power of 3.9 W. The output wavelength was measured by an InGaAs detector. It was centered at 1937 nm as shown in Fig. 4. Additionally, the output laser was linearly polarized.

We next proceeded to investigate the temperature sensitivity of the laser transitions by keeping the pump power fixed at 18.2 W and then varying the laser crystal heat-sink temperature, producing the data plotted in Fig. 5. Over various temperature ranges, a linear fit to the experimental data revealed that the output power decreased at 27 mW/°C.

With the pulse repetition rates (PRF) varying from 5 to 15 kHz, the Q-switched data were obtained. At lower PRF, the stability of the pulse energy was better and the pulse duration (FWHM) was narrower. Figure 6 shows the pulse duration at different repetition rates when the pump power was set at 18.2 W. As the repetition rate varied from 5 to 15 kHz, the pulse width increased from 80 up to 210 ns.

4. CONCLUSIONS

In summary, we have demonstrated an LD-pumped Q-switched Tm:YAP laser, which generated a 80-ns pulse width at a 5-kHz repetition rate with an average output power of 3.9 W centered at 1937 nm, corresponding to a slope efficiency of 29.4% and an optical conversion efficiency of 21.6%. We also investigated the temperature dependency of the output power and the pulse width at different repetition rates by keeping the pump power fixed. For further use, it was feasible to pump Ho:YAG and Cr^{+2}:ZnSe lasers, but further studies are needed.

ACKNOWLEDGMENTS

This work is supported by the Excellent Team program at Harbin Institute of Technology.

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